Using UV-C to Improve Indoor Air Quality and Save Energy

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ABSTRACT

The COVID-19 pandemic has brought to the fore the importance of improved air quality in occupied indoor environments. There is increasing consensus that improved air quality plays a crucial role in preventing airborne infections. The new ASHRAE 241 standard that was published in the summer of 2023, supports the use of UV-C with air quality measurement. In this paper, an overview of the different technologies for air filtration and purification is briefly reviewed. A review of the available studies on air treatment shows that Ultraviolet Germicidal Irradiation (UVGI) has the potential to reduce airborne microbial infections with efficacies up to 99.9% and is, therefore, a promising technology for air purification and therefore reduced energy consumption in HVAC systems. An analysis of test results of a combination of mechanical filters with minimum efficiency reporting values (MERV) of 8, 11, and 13, when combined with a commercially available high lamp intensity UV-C technology on the removal of *S. epidermidis, brasiliensis,* and *MS2* viruses is presented. Results show that combining a MERV 8 filter with the UV-C gives better performance than the MERV 13-only filter. The *S. epidermidis and MS2* viruses all reduced by greater than 99.99% for exposure times above 30 minutes with a combined MERV 8 and UV-C high lamp intensity, while *brasiliensis* reduced by 99.4% after 30 minutes for the same combination. Overall, there is potential for reduced airborne infections with the combined use of mechanical filters that only filter and block airborne microbial organisms and UV-C-based systems that work to deactivate and kill airborne microbial organisms.

1.0 Introduction

Indoor air quality is critical to human comfort and health. Several studies point to the increasing adverse health effects, death, hospital admissions, and asthma as the concentration of particles in the air increases (Brunekreef & Forsberg, 2005; Burger, 1990). Because the air in occupied spaces contains contaminants, i.e., particulate matter, gases, and vapors, it is essential that means of air recirculation or cleaning and purification are incorporated within the buildings HVAC systems. Over the past few years, there is increasing interest in improving air quality in indoor spaces to reduce infection rates. Aside from the COVID-19-causing virus, air purification and sterilization have been used for removing bioaerosols, a group of airborne particles of biological origin, including bacteria, fungi, and viruses. Before the COVID-19 pandemic, ASHRAE emphasized the need for air filtration and cleaning (Wargocki et al., 2015). This position document highlights the need to assess the effectiveness of HVAC technologies in reducing exposure to airborne contaminants to minimize the harmful effects on health and comfort. Moreover, ASHRAE recognizes the energy-saving potential of air filtration and cleaning compared to outdoor air ventilation.

Several filtration and air-cleaning technologies were evaluated in the ASHRAE position document on air filtration and cleaning by (Wargocki et al., 2015). These include mechanical filters, electronic filters, sorbent air cleaners, photocatalytic oxidation technologies, ultraviolet germicidal energy (UV-C), and packaged stand-alone air cleaners using a combination of different technologies (Wargocki et al., 2015). Of these methods, UV-C is considered to have the potential to inactivate viruses, bacteria, and fungi. Compared to other disinfection technologies, UV-C is considered economically affordable, easy to deploy, and can be strategically installed to effectively remove microbial pathogens with no production of harmful products (Pereira et al., 2023). Therefore, this paper focuses on the use of ultraviolet germicidal irradiation (UVGI), especially the short wavelength UV-C for air purification.

Besides improved indoor air quality, UV-C has been used for cleaning coils in air handling units (AHUs) of HVAC systems, reducing the biofilm formation, therefore ensuring consistent heat transfer efficiency and thus reducing energy consumption. In addition, this reduces the need for frequent coil cleaning and therefore reduces maintenance costs. For example, in a study on the use of UVGI on enhancing cooling coil energy performance in a hot and humid climate by Wang et al. (2016) showed a 9% reduction in energy consumption. The study also showed that savings in fan energy usage of the HVAC system were 39% more than the energy used by the lamps (Wang et al., 2016). In an experimental study at the University of Colorado Boulder, Luongo et al. (2017) showed an increase in the heat transfer effectiveness of between 3 and 6.4 % with the use of UV-C for coil cleaning. Yet another study of a typical office building in Philadelphia showed a reduction in fan energy use between 15 and 23% (Firrantello et al., 2013). Thus, UV-C disinfection has applications beyond indoor air quality improvements and the related reduction in energy consumption.

This paper reviews the operation principle of UV-C technology, provides a comparison between different lamp technologies, the efficacy of UV-C in reducing airborne infections, the potential reduction in energy consumption with reduced outside air, and the efficacy of a high-power induction-lamp-based air purifier.

2.0 UV-C operation principle

Unlike mechanical filters rated on how effective they remove particulate matter above 0.3 µm using the minimum efficiency reporting value (MERV), Ultraviolet disinfection (UV-C) degrades organic material and inactivates microbial organisms present in the air (Wargocki et al., 2015). As such, it does not use a filter unless it is added to remove the killed microorganisms.

Ultraviolet radiation has a wavelength extending from 100 – 400 nm, longer than x-rays but shorter than visible light. It is divided into three zones, i.e., UV-a between 320 nm – 400 nm, UV-b between 280 nm – 320 nm, and UV-c between 100 – 280 nm(First W. et al., 1999). UV-c is the most effective zone for disinfection, while the longer wavelength in UV-a is responsible for the tanning effect.

Far UV-C systems at 222 nm are considered non-harmful to human health and are safe to use for indoor-occupied spaces (Pereira et al., 2023). The inactivation of microbial organisms by UV-C is facilitated by the photochemical reactions caused by UV light on the genetic material of microorganisms (Pereira et al., 2023). This process inhibits the replication of RNA and DNA, inactivating the microorganisms. The maximum efficiency of inactivation is best achieved between 250 nm and 270 nm, a range which the nucleic acids of microorganisms absorb best.

Several light sources of different wavelengths are used in UV-C air purification systems. The table below gives the advantages and disadvantages of lamps used in UV-C systems, as presented in Pereira et al. (2023). LED and induction lamps offer the most benefits and almost the same lifespan. However, induction lamps are available in higher wattages and, therefore, intensities for microbial deactivation. Besides, LED lighting becomes more expensive as the wattage increases, which is not the case with induction lamps, making them much more suitable for high-wattage lamps for UV-C applications.

In addition to the need for a UV-C technology to operate near the optimal wavelength for microbial organism deactivation, it must meet UL 2998 requirements(UL Environment 2998, 2020). That is, it must be certified against the generation of any ozone. Ozone, also known as smog, is dangerous to human health when breathed and is harmful to the environment. As shown in Table 2.1, some UV lamps produce ozone and would not meet the UL 2998 requirements.

Table 2.1: Comparison of different UV-C light sources (Pereira et al., 2023).

UV-C light sources	Advantages	Disadvantages
Low-pressure mercury lamps (254 nm)	- High efficiency (30-40%) - Low cost - Technical maturity	- Mercury's environmental and health concerns - Significant warm-up time - Short life span (12-18 mo.) - Narrow operating temp range (18-27C)
Medium pressure (220 nm – 580 nm) and high-mercury lamps (220 – 1000 nm)	- Can emit a continuous spectral base overlapped	- Their high heat may require additional cooling systems, which increase equipment cost and security risk. - Possible ozone production
UV-C light-emitting diodes (265-280 nm)	- Disinfection efficacy - Application flexibility - Safety (do not use mercury) - Greater efficacy than conventional mercury lamps - Lower energy consumption and a longer lifetime - No warm-up time. - Continuous and pulsed	- Missing detectability - Unnoticed loss of up to 70% of intensity during usage - Low durability of the source - Low investment protection - Cannot achieve 253.7 nm UVGI wavelength.
Pulsed-xenon lamps (200 – 1000 nm with a peak at 254 nm)	- Power can reach 50 kW, leading to very high intensity in a single pulse. - Rapid - Effective treatment - No chemical residue - No peculiar odor	- High energy consumption - Critical heat dissipation
Excimer lamps (far-UV-C lamps at 222 nm)	- Effective inactivation of microorganisms and viruses - Reduced harm to exposed mammalian skin and eyes	- High energy consumption - Ozone production - Short lamp life (<1 years)
Induction lamps (253.7 nm)	- Longer life span (up to 10 years) - Highest UV-C production per Watt - Proven to mitigate all pathogens. - High efficiency of killing pathogens - No flickering or noise - Wide operating range (-20 to 100C)	- Higher first cost installation

To achieve a given inactivation or kill efficiency, the required UV irradiance it can be determined from (First. et al., 1999)

$$1-\eta=\frac{N_s}{N_o}=e^{-\kappa I\tau} \tag{1}$$

Where N_s is the number of particles that survived the UV-c unit, N_o is the number of particles exposed, κ is the UV-C inactivation rate in (cm^2/μW·s), I is the UV irradiance (μW/cm^2), and τ is the exposure time. The purification process aims to achieve an efficiency of η = 99.9%. Although inactivation rates higher than 90% can be achieved, the inactivation rate strongly depends on the type of microbial contaminant, specific species, and physical or mechanical factors of the technology used, including power intensity, the exposure or dwell time, lamp distance and placement and lamp life cycle and cleanliness, air removal, and movement patterns, temperature, relative humidity and air mixing, according to the ASHRAE position document (Wargocki et al., 2015).

The minimum equivalent clean airflow rate (V_{ECAi}) in the breathing zone of occupied spaces to alleviate long-range transmission risk in infection risk management mode (IRMM) is given by.

$$V_{ECAi}=ECAi\times P_{Z,IRMM} \tag{2}$$

Where ECAi is the equivalent clean airflow rate per person in IRMM in cfm or L/s and is given in ANSI/ASHRAE 241 (ASHRAE 241, 2023), and $P_{Z,IRRM}$ is the number of people in the breathing zone in IRMM. As an example, a classroom requires an ECAi of 40 cfm/person (ASHRAE 241, 2023). If there are 25 persons in this classroom, then V_{ECAi} in IRMM would be 1000 cfm.

The effectiveness of the air cleaning system, i.e., the infectious aerosol reduction rate in %, ε_{PR} determined by a single pass test, is used to determine the cleaning system's equivalent clean air flow rate (V_{ACS}) (ASHRAE 241, 2023).

$$V_{ACS}=\left[\frac{\varepsilon_{PR}}{100}\right]V_{RC} \tag{3}$$

Where V_{RC} is the recirculated airflow rate cleaned by the cleaning system in cfm. The infectious aerosol reduction rate, ε_{PR} *is* determined differently depending on how many systems are in series and for mechanical filters (ASHRAE 241, 2023).

For efficient removal of airborne microbial organisms, ASHRAE recommends the use of UV-C in conjunction with filters, with prefiltration before the UV-C lamp to protect lamps from particles and a mechanical filter after the lamps for microbial particles (Wargocki et al., 2015).

3.0 The efficacy of UV-C in mitigating airborne infections

Several studies have considered the efficacy of UV-C air purification or sterilization in mitigating airborne infections. Ethington et al. (2018) investigated the potential reduction in infection rates by removing bacteria from the air at room level using UV-C. A 12-month study completed in 2015 showed that airborne bacteria per m^3 of air in patient rooms was reduced by 42%. The study showed a dramatic decrease in infections pre-installation of UV-C compared to post-installation of UV-C. The study did not claim that this decrease was solely from using UV-C, but this shows the potential of UV-C air purification to reduce airborne infections. We should note that this was a low intensity UV-C bulbs and over the past few years some manufacturers are using high intensity lamps of up to 300W.

The application of UV-C in air purification has gained significant interest recently, especially to improve indoor air quality during the pandemic. In a recent study, Jutkowitz et al. (2023) investigated the benefits of UV-C air purification on COVID-19 outcomes in 80 nursing homes in Florida, Georgia, North Carolina, and South Carolina that installed ultraviolet air purification in their existing heating, ventilation, and air conditioning systems. The study showed that installing UV-C air purifiers reduced the number of COVID-19 cases per 1000 nursing home residents, and the probability of having any COVID-19 cases decreased following the installation.

A recent study by the Public Health Agency of Canada (PHAC, 2022) summarizes studies on the effectiveness and safety of ultraviolet germicidal irradiation technology in reducing SARS-CoV-2 in the air or occupied rooms. They presented results for cases of Ultraviolet Germicidal Irradiation (UVGC) technologies that can be used in rooms where people are present. These included wall-mounted UV-C lamps, UV-C ceiling fans, and portable UV-C air cleaners. In-duct mounted UV-C systems were not considered in the considered studies. Studies showed a reduction in the SARS-CoV-2 viral count by 90% in 6 minutes and 99% in 115 minutes with UV-C lamps. Another study showed a decrease in disinfection rates by over 90% with six wall-mounted UV-C lamps and 1 UVC- ceiling fan. The study also demonstrated that a high-power lamp rating was more effective than lower-power-rated lamps. A 55-W lamp inactivated the virus in 10 seconds compared to a 25-W lamp (PHAC, 2022). The same conclusions are presented by Farhad (2000) in the handbook on assessing the efficacy of ultraviolet germicidal irradiation and ventilation in removing mycobacterium tuberculosis. The percentages of particles inactivated at the first minute increased from 35%, 60%, and 80% as the power output increased from 10 W to 20 W and 40 W. Increasing the power from 10 to 20 W increased the inactivation rates from 65% to 90% after 5 minutes, while an increase from 20 to 40 W gave a 94% inactivation rate after 5 minutes. The handbook also investigated the effect of air changes on the percentage of particles inactivated or vented out. In this arrangement, particles are removed by ventilation and UV-C. It is demonstrated that UVGI removes more particles than the ventilation system, except in cases where the air changes per hour were higher. This is a potential benefit of using UV-C for air purification, reducing the ACH and, therefore, the energy needed for cooling or heating the indoor space.

ASHRAE has recognized that the UV-C wavelength inactivates virtually all microorganisms living on HVACR surfaces, with inactivation ratios of up to 99 percent, depending on the intensity of the UV-C and the length of exposure. A recent study notes the availability of UV-C technology with pathogen reduction rates higher than 99.9% (Pereira et al., 2023).

With the increasing interest in applying UV-C technology for air purification, an ASHRAE standard, i.e., ASHRAE 241-2023, was recently developed. It establishes a minimum requirement for controlling infectious aerosols and reducing the risk of disease transmission in new and existing buildings. Included are outdoor air and air cleaning system design, installation, commissioning, operation, and maintenance requirements to reduce exposure to infectious aerosols.

Despite the evident benefits of using UV-C in the literature, extra caution is needed for air-cleaning technologies that emit ozone rather than using it for air cleaning. Ozone has been shown to have adverse health effects, as such devices that use the reactivity of ozone for cleaning are not recommended for occupied spaces Wargocki et al., (2015). Moreover, Memarzadeh et al. (2010) indicate that UV-C should be considered in a healthcare setting only in conjunction with other well-established technology, such as a proper HVAC system, dynamic removal of contaminants, and preventive maintenance and cleaning of the care environment. Moreover, the installation of UV-C in conjunction with high-efficiency filtration has the potential to improve air quality significantly. Smaller microbes that are difficult to filter would be inactivated by UV-C exposure, and larger microbes, such as spores that are resistant to UV-C, are filtered out by the filters used. Some UV-C manufacturers have received the UL2998 for zero ozone emissions. We would recommend that this testing protocol be added to the specification when selecting a UV-C system.

Safety considerations are essential when choosing a UV-C air purification technology to use. Among the concerns are exposure to UV wavelength greater than 230 nm which can penetrate and damage the skin and eye tissue (PHAC, 2022). Moreover, some UV-C systems have ozone, exposure to which can cause headaches, coughing, dry throat, shortness of breath, a heavy feeling in the chest, and fluid in the lungs (NIOSH, 2023). As such, UV-C technology, where ozone exposure is unavoidable, is not recommended. Mercury exposure is another potential health hazard possible with the use of UV-C air purification, especially lamps that contain mercury would be difficult to dispose off.

4.0 Air purification vs. ventilation and energy consumption

To minimize airborne infections, it is essential to ensure that indoor occupants are exposed to excellent air quality. In ventilation-only systems, this is achieved by supplying fresh air. During the COVID-19 pandemic, studies showed that providing 100% fresh air to indoor environments significantly reduced the infection risk of SARS-CoV-2 (Lin et al., 2023; Srivastava et al., 2021). The amount of energy used by an HVAC system significantly depends on the volume of air ventilated into and out of the building. During cold periods, outdoor air must be heated to the required temperature and conditioned to the proper humidity. In fact, waste heat recovery systems show significant energy savings by recovering heat from exhaust air and using it to preheat incoming outdoor air (Zemitis & Borodinecs, 2019). Based on the new ASHRAE 241 standard an air purification using UV-C technology could reduce the number of air changes per hour, leading to significant energy savings.

More often we are seeing the outdoor air is not suitable to bring into a building due to the Air Quality Index (AQI) to be much higher then inside the building. We are becoming much more aware these numbers this season due to the increased forest fires. We measure these fine particulates through a rating called PM2.5. PM2.5 is defined as particles that are 2.5 microns or less in diameter. The largest PM2.5 particles are about 30-times smaller than a human hair. The AQI for PM2.5 is measured as fine particles μg/m^3. The AQI is divided into six categories. Each category corresponds to a different level of health concern.

AQI Basics for Ozone and Particle Pollution

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general pubic is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Onsite testing of PM2.5 is not currently common however ASHRAE 241 calculations require this measurement of the inside and outside air quality. These devices have become cost effective and would communicate the PM2.5 of each back to the building automation system. Many times, the outside air (O/A) dampers could be closed and save energy when the inside environment is clean.

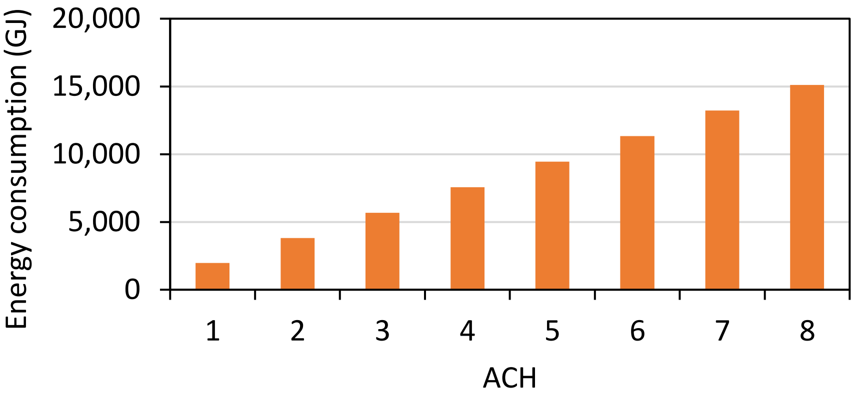
In-duct UV-C systems have shown the potential to inactivate SARS-CoV-2; depending on the design and dosage of UVGI, inactivation rates up to 100% can be achieved. (Luo & Zhong, 2021). Recommended UVGI dosage of at least 4.64 J/m^2 and 5.84 J/m^2 for 90% SARS-CoV-2 and SARS-CoV inactivation (Luo & Zhong, 2021). For in-duct systems, slower air flow rates are required to increase UV dose in ductwork, and more powerful lamps are recommended.

The amount of energy savings with the use of UV-C can be determined by considering the reduction in outdoor air ventilation rates and increasing recirculated cleaned air flow rates. The air changes per hour (ACH) for a given space can be determined from recommended flow rates per person or per ft^2 of the occupied space. Where,

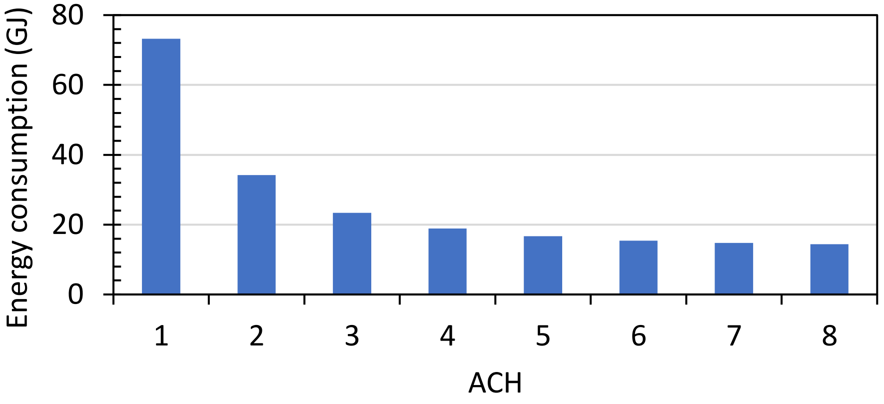
$$ACH = \frac{\text{outdoor air in (ft}^3\text{ per minute)}\times 60\text{ (minutes per hour)}}{\text{Volume (ft}^3\text{)}} \tag{3}$$

The minimum ventilation rates for non-residential and residential buildings in ANSI/ASHRAE 62.1 and 62.2 can be used to determine the required ACH for any space. The required breathing zone ventilation rates vary depending on building type, from 5 cfm to 20 cfm per person, and 0.06 and 0.48 cfm/ft^2 for non-residential buildings, and 0.03 cfm/ft^2 and 7.5 cfm per occupant for residential buildings. Higher values are specified for specific indoor spaces where pollution is higher. Generally, ACH > 5 is recommended. However, with the recent pandemic, ACH of 6 is deemed better, and ACH > 6 is recommended as the best for schools, with cfm/person of 30 and greater than 30 being deemed as better and best, respectively (The Lancet COVID-19 Commission, 2022)

An energy analysis considering different mechanical ventilation rates provides an insight in the energy savings from reduced outdoor air supply. In the case of UV-C air cleaning, indoor air is purified and recirculated, and a minimum amount of outdoor air is let into the indoor spaces. A simple energy model of a 35,100 ft^2 school located in Calgary has been used to determine the influence of air changes per hour energy consumption. As figure 1 shows, the energy consumption significantly increases as the amount of outdoor air increases. For a recommended ACH of 5, the energy consumption increased by 150% from an ACH of 2. The cooling load follows an opposite trend, as the ACH increases, the energy required to cool the air to the required temperature reduces. This is because Calgary is considered a heating-dominant region, and summer temperatures are rarely that hot. Moreover, for the school modeled, the HVAC system was scheduled not to operate in the summer months of June, July, and August when schools are closed. Overall, considerable energy savings can be achieved with air purification/cleaning compared to mechanical ventilation since the heating loads in this case are much higher than cooling loads. The same is true in a hotter climate since cooling loads will increase with mechanical ventilation rates.



(a) Heating



(b) Cooling

Figure 1: Variation of energy consumption with mechanical ventilation rates in a school (a) heating energy consumption, and (b) cooling energy consumption

The analysis of energy consumption shown in Figures 1(a) and (b) considers potential savings with the reduction in outdoor air. As discussed earlier, there are potential energy savings with UV-C disinfection of coils in the air handling units of HVAC systems from high heat transfer rates. Additional benefits include cost savings with reduced frequencies of coil cleaning for systems with UV-C disinfection of coils in AHUs of HVAC systems.

5.0 Applicable codes and standards

ASHRAE standards provide requirements for ventilation and indoor air quality. Before ASHRAE 241, ASHRAE 62.1, the standard for Ventilation and Acceptable Indoor Air Quality, was used as a basis for determining ventilation rates. However, ASHRAE 241's rates significantly increase from current ventilation clean air requirements.

Table 5.1 provides the equivalent airflow rates in the breathing zone for different occupancy categories to control infectious aerosols (ASHRAE Standard 241-2023)

Occupancy Category	241 Equivalent Clean Airflow (lps/person)	Calculated Equivalent Air Changes per Hour	Calculated Equivalent CO2 (ppm)	62.1 Outdoor Air ventilation rate (lps/person)
Restaurant	30	28	600	5.1
Gym	40	3.7	770	22.9
Office	15	1	790	8.5
Retail	20	4	850	7.8
Elementary School	20	6.7	600	7.4
Lecture Hall	25	50	620	4
Manufacturing	25	2.3	770	17.9
Warehouse	10	0.1	1300	35
Health Care Exam Room	20	5.3	700	–
Health Care Waiting Room	45	30	540	–
Place of Religious Worship	25	40	620	2.8
Residential Dwelling Unit	15	0.4-3	710	–

ANSI/ASHRAE 241 highlights that equivalent clean airflow requirements for a space or system can be met by a combination of sources, including outdoor air, filtered recirculated air, and air disinfected by various technologies (ASHRAE 241, 2023). With this flexibility, the standard does not rigidly dictate how compliance can be achieved. Besides, controls can be optimized to ensure reduced cost and energy savings. Specifically, with recirculated purified air, significant energy savings can be achieved with reduced heating or cooling requirements. Thus, UV-C and other air purification or filtration technologies have the potential for energy cost reduction as less outdoor air would be added to the occupied spaces. UV-C can be used for

- in-duct surface and air disinfection.
- upper air or upper room decontamination; and
- mobile roll-in-the-room systems.

The volume and velocity of air traveling through an HVAC system significantly impact the length of exposure to the germicidal wavelength (residence time)—a higher volume of air and/or faster-moving airstreams require greater UV intensity. Similarly, air temperature (cold air reduces the output of UV-C lamps), humidity (high RH decreases pathogen susceptibility to UV-C), and duct reflectivity all play a role in determining the amount of UV-C energy necessary in any given application.

For upper room UV fixtures, the only consideration is a ceiling that is at least 8 ft (2.44 m) or higher and that the upper room area where the UV-C energy will be installed is free of obstructions (hanging televisions, signage, framing soffits, etc.) that might misdirect the UV energy.

6.0 High-intensity UV-C air purifier

As with all things in life, every item is not created equal. Same is true in selecting a UV-C product. Some units provide 10W while others are as much as 300W. This section analyzes the test results of a 300W UV-C air purifier from available test data and supplier-provided resources. The lamp used in the test is an induction lamp versus others that may use mercury-based lamps. As such, there are no negative impacts associated with conventional light sources, including short lifespans, frequent replacement, toxicity and environmental concerns, and significant warm-up times. According to manufacturer product data, the lamp requires replacement every 7-10 years and makes no ozone (UL 2998 certified).

(a) Assembled (b) Lighting system

Figure 1: Induct 300 W

A recent independent investigation by Airmid Health Group based in Ireland, assessed the efficacy of various technologies to remove airborne *Staphylococcus epidermidis* and *Aspergillus brasiliensis* from two linked environmental test chambers (Airmid Health Group, 2023). The tests were conducted using two air chambers built to comply with American Society for Testing and Materials (ASTM) standard. Both chambers were supplied with HEPA-filtered supply air. Tests were for air changes per hour ranging from 0.5 to 20 and a wide range of selected temperatures and humidity levels. An UV-C unit was combined with different mechanical filters of different minimum efficiency reporting values (MERV) i.e., MERV8 and MERV13.

Figure 2 shows the reduction in the S.*epidermidis* during the tests in the two chambers for a MERV8 filter combined with a UV-C unit. The figure shows that this combination reduced the S.*epidermidis* by 92.81% in 7.5 minutes, by 99.87 in 15 minutes and greater than 99.99% after 30 minutes.

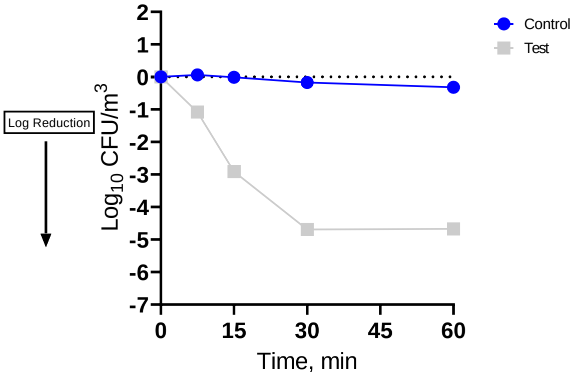


Figure 2. Reduction of S.epidermidis in the two chambers during tests for a combined MERV8 filter and 300W UV-C: adopted from test report (Airmid health group, 2023).

A MERV 13 and a 300W UV-C did not show significant changes in the percentage reduction rates. Figure 3 shows the reduction in the S.*epidermidis* during the tests in the two chambers for a MERV 13 filter combined with a 300W UV-C. As shown in the figure, the S.*epidermidis* reduced by 94.66% in the first 7.5 minutes, 99.92% in 15 minutes and 99.99% in 30 minutes. No changes were observed after 30 minutes.

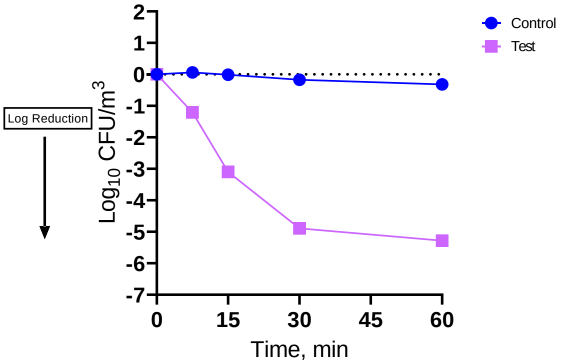


Figure 3. Reduction of S.epidermidis in the two chambers during tests for a combined MERV 13 filter and 300W UV-C: adopted from test report (Airmid health group, 2023).

In all cases, a combination of the UV-C and any of the filters resulted in reductions of the S.epidermidis relative to a MERV 13 filter as shown in Figure 4.

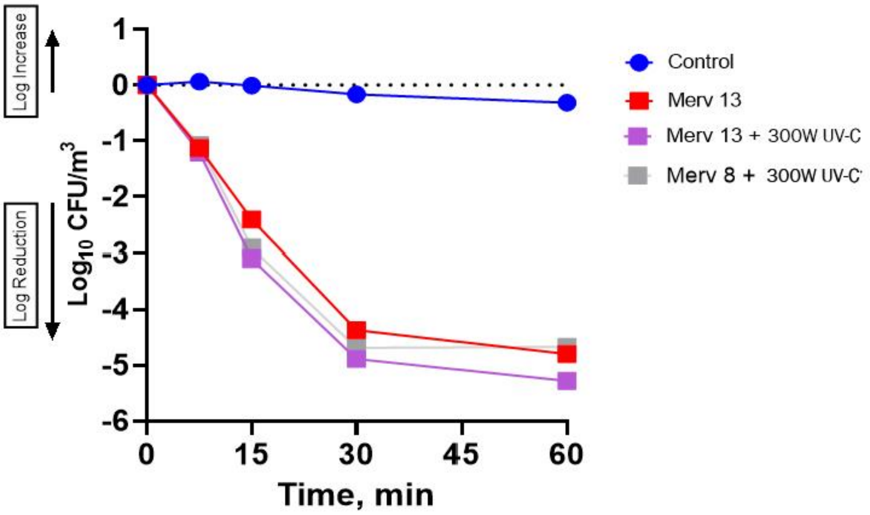


Figure 4. Reduction of S.epidermidis in the two chambers during tests for different technology combinations: adopted from test report (Airmid Health Group, 2023).

Figure 5 shows the reduction in the Bacteriophage MS2, a non-enveloped virus which is a single-stranded RNA virus like SARS-CoV-2. It is 27 nm in diameter compared to 120 nm of the SARS-CoV-2 viruses. As shown, combining a 300W UV-C with any of the filters reduces the MS2 virus. It should be noted that according to the tests by Airmid health group (Airmid health group, 2023), a MERV 13 only filter reduces MS2 by 94.16% in 7.5 minutes, by 99.73% in 15 minutes and by greater than 99.9% in 30 minutes, whereas a combination of MERV 8 and a 300W UV-C reduces MS2 virus by 87.20% in 7.5 minutes, by 99.68% in 15 minutes and by greater than 99.99% in 30 minutes and a MERV 11 and a 300W UV-C results in 93.41% reduction of the MS2 virus in 7.5 minutes, by 99.4% in 15 minutes and by greater than 99.99% in 30 minutes.

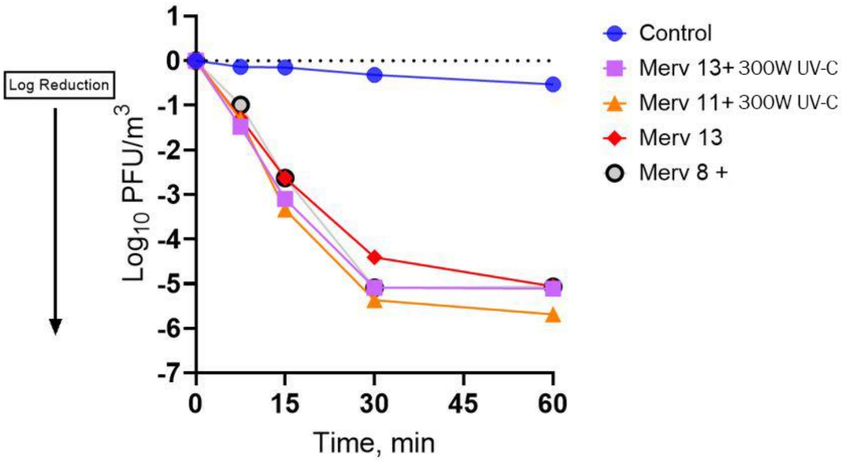


Figure 5. Reduction of MS2 in the two chambers during tests for different technology combinations: adopted from test report (Airmid Health Group, 2023).

7.0 Conclusion

ASHRAE 241 represents a significant step forward in our understanding how to improve our buildings IAQ and save energy at the same time. It is now up to building owners, operators, and the wider industry to adopt these new standards and contribute to creating safer indoor environments for all. It starts with hiring an HVAC engineer to create a Building Readiness Plan (BRP).

In most cases a building can become 241 compliant by simply adding air quality measuring (PM2.5) with CO2, add UV-C induction lamps in air systems and then ensuring that the ducting is clean with a high-quality mechanical filter. When we reviewed an office space in Calgary, we believe that the 241-complaint building will save almost $1/ft^2$.

Studies on the efficacy of UV-C in inactivating microbial organisms have been highlighted. Inactivation rates up to 99.9% have been demonstrated in the reviewed studies, depending on the dosage of the UV-C technology, the power of the lamp, the exposure time, and the airflow rate, among others.

Below are the following codes and standards that are applicable when specifying a UV-C system:

1. UL 2998 – Environmental Claim Validation Procedure (ECVP) for Zero Ozone Emissions from Air Cleaners
2. IEC 62471 – Photobiological Safety of Lamps and Lamp Systems
3. IEC 60335-1, Annex T – Household and similar electrical appliances - Safety
4. UL 1598 – UL Standard for Safety Luminaires
5. ANSI/IES RP-27 – Recommended practice for photobiological safety for lamps and lamp systems – General requirements
6. UL CAP – Cybersecurity Assurance Program for healthcare facilities
7. NFPA 70 – US National Electric Code
8. CSA C22.1-2021 – Canada Electric Code
9. ASHRAE Standard 52.2

References

Airmid health group. (2023). *Assessment of the relative efficacy of various technologies to remove airborne Staphylococcus epidermidis and Aspergillus brasiliensis from two linked environmental test chambers*.

ASHRAE 241. (2023). *Control of Infectious Aerosols*. www.ashrae.org/241-2023

Assessing the Efficacy of Ultraviolet Germicidal Irradiation and Ventilation in Removing Mycobacterium Tuberculosis Number of Viable Particles Varying with Time (UV3). (n.d.).

Brunekreef, B., & Forsberg, B. (2005). Epidemiological evidence of effects of coarse airborne particles on health. *European Respiratory Journal*, *26*(2), 309. https://doi.org/10.1183/09031936.05.00001805

Burger, H. (1990). Bioaerosols: Prevalence and health effects in the indoor environment. *Journal of Allergy and Clinical Immunology*, *86*(5), 687–701. https://doi.org/10.1016/S0091-6749(05)80170-8

Ethington, T., Newsome, S., Waugh, J., & Lee, L. D. (2018). Cleaning the air with ultraviolet germicidal irradiation lessened contact infections in a long-term acute care hospital. *American Journal of Infection Control*, *46*(5), 482–486. https://doi.org/10.1016/J.AJIC.2017.11.008

Evidence on the effectiveness and safety of ultraviolet germicidal irradiation technologies in reducing SARS-CoV-2 in the air of occupied rooms. (2022).

Firrantello, J., DeGraw, J., & Bahnfleth, W. (2013). Modeled Air Quality and Energy Use Impacts of UVGI for Cooling Coil Biofouling Mitigation. *ASHRAE IAQ*, 207–214.

First W., M., Nardell A., E., Chaisson, W., & Riley, R. (1999). Guidelines for the Application of Upper-Room Ultraviolet germicidal irradiation for preventing transmission of airborne contagion - part I - basic principals. *ASHRAE Transactions*, *CH-99-12-1*.

Jutkowitz, E., Shewmaker, P., Reddy, A., Braun, J. M., & Baier, R. R. (2023). The Benefits of Nursing Home Air Purification on COVID-19 Outcomes: A Natural Experiment. *Journal of the American Medical Directors Association*, *24*(8), 1151–1156. https://doi.org/10.1016/J.JAMDA.2023.05.026

Lin, Y., Wang, J., Yang, W., Tian, L., & Candido, C. (2023). A systematic review on COVID-19 related research in HVAC system and indoor environment. *Energy and Built Environment*. https://doi.org/10.1016/J.ENBENV.2023.07.009

Luo, H., & Zhong, L. (2021). Ultraviolet germicidal irradiation (UVGI) for in-duct airborne bioaerosol disinfection: Review and analysis of design factors. *Building and Environment*, *197*, 107852. https://doi.org/10.1016/J.BUILDENV.2021.107852

Memarzadeh, F., Olmsted, R. N., & Bartley, J. M. (2010). Applications of ultraviolet germicidal irradiation disinfection in health care facilities: Effective adjunct, but not stand-alone technology. *American Journal of Infection Control*, *38*(5), S13–S24. https://doi.org/10.1016/J.AJIC.2010.04.208

Ozone | NIOSH | CDC. (n.d.). Retrieved August 17, 2023, from https://www.cdc.gov/niosh/topics/ozone/default.html

Pereira, A. R., Braga, D. F. O., Vassal, M., Gomes, I. B., & Simões, M. (2023). Ultraviolet C irradiation: A promising approach for the disinfection of public spaces? *Science of The Total Environment*, *879*, 163007. https://doi.org/10.1016/J.SCITOTENV.2023.163007

Srivastava, S., Zhao, X., Manay, A., & Chen, Q. (2021). Effective ventilation and air disinfection system for reducing coronavirus disease 2019 (COVID-19) infection risk in office buildings. *Sustainable Cities and Society*, *75*, 103408. https://doi.org/10.1016/J.SCS.2021.103408

The Lancet COVID-19 Commission. (2022). *Proposed Non-infectious air delivery rates (NADR) for reducing exposure to airborne respiratory infectious disease*.

UL Environment 2998. (2020). *Environmental claim validation procedure (ECVP) for zero ozone emissions from air cleaners* (pp. 1–8).

Wang, Y., Sekhar, C., Bahnfleth, W. P., Cheong, K. W., & Firrantello, J. (2016). Effectiveness of an ultraviolet germicidal irradiation system in enhancing cooling coil energy performance in a hot and humid climate. *Energy and Buildings*, *130*, 321–329. https://doi.org/10.1016/J.ENBUILD.2016.08.063

Wargocki, P., Kuehn, T. H., Burroughs, H. E. B., Muller, C. O., Conrad, E. A., Saputa, D. A., Fisk, W. J., Siegel, J. A., Jackson, M. C., Veeck, A., & Francisco, P. (2015). *ASHRAE Position Document on Filtration and Air Cleaning*. www.ashrae.org

Zemitis, J., & Borodinecs, A. (2019). Energy saving potential of ventilation systems with exhaust air heat recovery. *IOP Conference Series: Materials Science and Engineering*, *660*(1). https://doi.org/10.1088/1757-899X/660/1/012019